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Effects of deficit irrigation on some physiological traits, production and fruit quality of 'Mazafati' date palm and the fruit wilting and dropping disorder

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ABSTRACT

Date palm (*Phoenix dactylifera* L.) fruit wilting disorder, caused by the high increase in temperature and decrease in relative humidity of the environment, is more prevailing due to climate change over the last decades. This has affected negatively the economy of single-product palm growers. The physiological effects of deficit irrigation on 'Mazafati' date palm during four months, starting from two months before flowering (early January) up to two months after flowering which is concomitant with the middle of the Kimri stage (late April) was investigated. Two irrigation levels of 100% ETc and 70% ETc at three irrigation intervals of 50, 100 and 150 mm cumulative evaporation in two locations with different average daily and annual temperatures in Sistan and Baluchestan province of Iran were compared. Deficit irrigation at intervals of 100 mm evaporation resulted to the highest bunch weight and yield in two orchards and, the highest water use efficiency was obtained in the location 2 (warmer area). Wilting percentage of bunch was not affected by irrigation levels, but the irrigation interval at 100 mm evaporation showed the best control. The increase in mean weight of fruit was observed only in the location 1 with irrigation intervals of 50 and 100 mm evaporation. The highest amount of soluble solids and soluble sugars was obtained in the second location with irrigation interval at 150 mm evaporation. Total phenolic compounds and fruit starch showed the lowest and highest with full irrigation, respectively. Deficit irrigation at all three irrigation intervals increased the activity of peroxidase and polyphenol oxidase in fruits and leaves. Reduction of calcium and iron of leaf during the disorder was observed with deficit irrigation at different irrigation intervals. However, reduction in leaf zinc was observed only at 150 mm irrigation interval. According to the results, irrigation level of 70% with 100% did not show a significant difference in fruit qualitative properties, and irrigation at 100 mm evaporation intervals before the disorder risk period is recommended to control the disorder. It seems to be a more increasing in percentage or duration of deficit irrigation on date palm in future researches to be promising.

1. Introduction

Date palm (*Phoenix dactylifera* L.) fruit wilting disorder has become the main problem to date growers in the last two decades. The reasons for this phenomenon is falling the relative humidity to less than 20% and the increase in temperature to over 45 °C accompanied with hot winds, occurring during the Khalal into the Rotab fruit growth stages. This will cause the whole fruits of bunch to drop within ten days. The bunches and stalks that are not in this phase of fruit growth due to later fertilization, are not affected (Mireei and Sadeghi, 2013).

Deficit irrigation (DI) is referred to as water restriction in certain growth periods of the plants, and was first used in the 1980s as a way to limit vegetative growth of peaches and save water. DI reduces mainly the vegetative growth of trees and as a result reduces the competition of vegetative and reproductive growth and significantly reduces the cost of orchard operations. This reduction in costs can, in some cases, offset a reduction in profits due to the reduction in the size of the fruit (Chalmers, 1981). The use of DI in controlling diseases and improving the quality of the fruit is less considered. For example, one of its positive results is the reduction of cadmium in fruits (Benavides et al., 2005). It also controls the physiological disorders of blossom end rot in tomato and bitter pit in apple which are due to calcium deficiency in fruit, and also botrytis bunch rot disease in grapes (Austin and Wilcox, 2011; Mpelasoka et al., 2001; Zegbe-Domınguez et al., 2003). Date bunch wilting disorder have been damaging soft dates for many years.

If DI properly programmed, no or less negative effects will occur. The sensitivity of flower buds to water deficiency is different during the flowering period and thereafter. In peaches due to flower induction and

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fruit growth, early September in the northern hemisphere represents the time of transition from sensitivity, and then the sensitivity decreases. In the late ripening cultivars of stone fruits, the lag phase of fruit growth of (pith hardening) is a suitable period for reduced irrigation. During this period, the growth of fruits is slow and with applying DI, the growth of the shoots will decrease and the fruit content will improve (Naor, 2005). The best results in pistachio achieved when a DI equivalent of ETc 50% applied in the second stage of fruit growth (full shell expansion to the onset of rapid kernel growth) and ETc 25% after harvest. The most stressful period in pistachio begins with the onset of the third stage or rapid kernel growth (Goldhamer and Beede, 2004). The induction of persimmon flowers is in the summer of previous year and the differentiation of flower organs will occur the current season until flowering, so the effect of DI during flowering, fruit set, and the first half of May (beginning of flower induction for next season), will affect the yield and the size of the fruit in the current and next season (Kanety et al., 2014). For 'Conference' pear complete irrigation until harvest and up to two weeks after harvesting and then DI until the stage of leaf fall is recommended, because, in contrast to the control, it maintained yield and fruit quality of the next year by storing. (Marsal et al., 2012).

Reduced irrigation of dates, increased water productivity, as well as the beneficial effects on early ripening and reducing the contamination by the fungus *Fusarium proliferratum* and reduced fruit dropping (Gribaa et al., 2013; Hillel, 2013). For this, DI has been used in the range of 65–75% of full irrigation based on evapotranspiration measurements. Different cultivars and different stages of date fruit growth have shown different sensitivity to DI (Liebenberg and Zaid, 1999). During the development of the bunch and its rachis, the date fruitlets grow slowly and probably do not require a large volume of water. In contrast, after the end of the rachis growth (2nd half of April), there is a rapid increase in the fruit size, so it is expected that DI during this phenological stage will lead to small fruits and a decrease in yield, hence, palm growers should be warned for not limiting water supply during this period (Gribaa et al., 2013). Considering the mentioned report, in present research, DI during a four-month period was applied for the control of the 'Mazafati' date bunch wilting, while, the physicochemical parameters of fruit and the antioxidants and stress marker changes were considered.

2. Materials and methods

2.1. Plant materials and experimental design

During the growing season in 2017, two orchards of 10–12 year-old 'Mazafati' date (8 × 8 m) with a history of bunch wilting were selected in two regions of Sistan and Baluchestan province of Iran.

The geographic and climatic characteristics of the two studied locations are shown in Table 1. Selected palm trees were pollinated with pollen of M003 genotype in both locations and tried to be under uniform orchard operations throughout the season. After the fruit set (about 4 weeks after pollination), the number of bunches was adjusted to 8 per palm tree. Determination of the amount of water delivered to the plants was estimated according to the Penman-Monteith equation and was distributed to the trees by volume meter. The amount of plant evapotranspiration (ET_C) in this method is: ETc = ETo.Kc, where ETo is reference evapotranspiration and Kc is crop coefficient and its value was determined according to the values provided for the dates by the FAO (Allen et al., 1998). Irrigation water was delivered through a Babbler system with an average of 4.5 liters per minute around the palms. Irrigations were applied for intervals of 50, 100 and 150 mm cumulative evaporation (P50, P100, and P150) at two irrigation levels of 70% (V70) and 100% (V100) ETc for four months from 2 months before bunching up to two months after it (mid stage of Kimri). Before and after this period, irrigation was carried out with the usual amount and interval of the area (7–10 days in warm months and up to 24–27 days in cool months). The amount of water delivered to the plants, the applied crop coefficient and the irrigation dates during the mentioned period are given in Table 2. At the harvest stage (Rutab), all bunches were harvested from each tree and the total weight of the fruits were recorded. Water-use efficiency (WUE) was calculated as fresh date palm yield in each tree divided by total year irrigation water applied. Five strands of each brunch from four bunches were randomly assigned in each tree at four directions, and the number of fruits after fruit set were recorded in these strands. The number of dried and dropping fruits were recorded at each stage of fruit growth till harvest time and expressed as percentage. Sampling of leaflets from the middle of the leaves around each tree in the stage of disorder (50% drying and dropping during the Khalal up to Rutab stage) was carried out to measure the mineral elements. Fruit samples (20 fruits of each bunch) were collected at the Rutab stage to determine the physicochemical parameters. Fruit samples and leaf samples adjacent to the bunch were collected for measuring enzyme activity. Collected fruit and leaf samples were frozen immediately and kept at -80 °C for the biochemical measurements.

2.2. Determination of physical and biochemical traits

Fruit firmness was measured (kg/cm^2) at one or two points on the equatorial zone of date fruits by applying a plunger of 3 mm in diameter, using a penetrometer TA-XT2 (Stable Microsystems Texture Technologies Inc., UK). Add distilled water to fruit flesh and then centrifuge it and finally total soluble solids (TSS) of fruit juice were obtained as brix degree (Brix°) with a digital refractometer (DR 6000, A. Kruss Optronic GmbH, Hamburg, Germany). Total acids were indicated by titration with 0.1 N sodium hydroxide in the presence of phenolphetalein as indicator, and the percentage of total acids was obtained as equivalent to malic acid content (Horwitz, 2000). For measurement of total phenolics, Folin–Ciocalteu reagent was used. Total phenolics were calculated from a calibration curve obtained by the absorbance of known concentrations of gallic acid at 750 nm after reacting with the reagent. Phenolics content was expressed in milligrams per gram dry weight (mg g^{-1} DW) (Velioglu et al., 1998). Soluble sugar contents were determined according to the phenol–sulphuric acid method (Dubois et al., 1956). Starch contents were determined according to McCready et al. (1950).

Table 1
Geographical and climatic characteristics of the two studied locations.

Locations (L)	Latitude (N)	Longitude (E)	Altitude (m)	Annual Precipitation (mm)	Absolut Max Temperature (°C)	Absolut Min Temperature (°C)	Average Annual Temperature (°C)	Average Wind Speed (km/h)	Mean Annual Relative Humidity (%)	EC of irrigation water (dS/m)
L_1 (Bampour)	27° 09′	60° 40′	491	110.2	50	−6.2	26.9	7.59	30	1.9
L_2 (Nikshahr)	26° 12′	60° 12′	456	169.5	49.6	2.8	28	10.37	44	2.2

Table 2
The crop coefficient (Kc), irrigation dates and water requirement (WR) (mm) for each 'Mazafati' date tree under two irrigation levels (100% and 70% ETc) at two locations (L_1 and L_2).

Month	Kc	Irrigation dates						WR (100%)		WR (70%)	
		L_1			L_2			L_1	L_2	L_1	L_2
		P50	P100	P150	P50	P100	P150				
January	0.95	–	–	–	18	–	–	31.2	56.2	21.8	39.3
February	0.9	3	–	–	14	14	–	25.0	37.5	17.5	26.2
March	0.9	9 and 20	9	20	6 and 17	17	6	85.9	95.3	60.1	66.7
April	0.91	4,14, 21 and 29	4 and 21	21	1, 10, 15, 23 and 28	10 and 23	10 and 28	142.1	151.5	99.4	106.0
Total Months of reproductive growth	–							1045.3	1126.5	976.8	1052.5
year	–							1470.1	1581.6	1384.7	1479.3

2.3. Enzymes extraction and activity assays

2.3.1. Enzymes extraction

Antioxidant enzymes activities of fruits and leaves were determined spectrophotometrically. Half a gram of fresh tissue was homogenized in 2 ml extraction buffer (0.607g Tris, 0.05g polyvinyl pyrolidine, made up to 50 ml with distilled water, pH: 8). The homogenates were centrifuged at 15,000 rpm for 15 min at 0–4 °C, and the supernatants were used for determining catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD) enzymes activities. The extraction buffer for polyphenol oxidase (PPO) contained 5 mM Tris − HCl (pH 7.2), 0.25 M sucrose, and 1 mM $MgCl_2$ (Qaddoury and Amssa, 2003). In all assays, the measurements with the boiled enzyme extracts were taken as the controls.

2.3.2. Antioxidant enzymes activity assays

For measurement of POD activity (EC 1.11.1.7), the reaction mixture contained 20 mM potassium-phosphate buffer (pH = 6.0), 5 mM guaiacol, 5 mM H_2O_2 and 0.67% of enzyme extract in a final volume of 3 ml. Oxidation of guaiacol was measured by determination of the increase in absorbance at 470 nm for 1 min (Zhou and Leul, 1999). The reaction mixture for SOD (EC 1.15.1.1) assay was prepared by mixing 50 µl crude enzyme extract with the SOD assay solution (50 mM potassium phosphate buffer [pH: 7.8], 75 mM nitroblue tetrazolium [NBT], 13 mM L-methionine, 0.1 mM EDTA and 2 µM riboflavin). Reaction was carried out in test tubes at 25 °C under shaking and illumination of a fluorescent lamp for 15 min. One unit of enzyme activity was determined as the amount of enzyme needed for inhibition of 50% NBT reduction by monitoring absorbance at 560 nm (Beauchamp and Fridovich, 1971). PPO activity (EC 1.14.18.1) was determined by measuring oxidation of catechol. The enzyme extract (0.2 ml) was rapidly added to 2.8 ml of 20 mM catechol solution prepared in 0.01 M sodium phosphate buffer (pH: 6.8). The increase in absorbance at 400 nm and 25 °C was recorded for 3 min (Li and Steffens, 2002). CAT activity (EC 1.11.1.6) was measured by 2.5 ml of substrate solution made of 25 mM H_2O_2 in a 75 mM sodium phosphate buffer pH: 7.0 and enzyme extract. The decrease in absorbance at 240 nm and 25 °C was recorded for 1 min intervals (Bergmeyer et al., 1974).

2.4. Mineral analysis of leaves

The collected leaflet samples were washed with distilled water, and oven dried for 48 h at 65 oC in paper bags. Samples were ground and wet digested as described by Chapman (Chapman and Pratt, 1961). Nitrogen (N) was analyzed by micro-Kjeldahl procedure. Phosphorus (P), Calcium (Ca), Magnesium (Mn), Copper (Cu), Zinc (Zn) and Iron (Fe) elements were determined by Atomic Absorption spectrophotometer (Perkin Elmer, 3110). Potassium (K) concentration was determined by emission flame photometer.

2.5. Statistical analysis of data

This research was conducted as a factorial (main factors the amount and intervals of irrigation) in a randomized complete block design with four replications in two locations combined and comparison of the means were analyzed by SAS statistical software (version 9.4) using LSD at 0.05 level (Selahvarzi et al., 2017). Comparison of the means in terms of variance analysis were in three ways: 1) If the interaction of the location × irrigation intervals × irrigation amount in each parameter was significant, all treatments in both locations were compared together. In present study, this case was not observed with the mean of any parameters. 2) If the interaction between the location × irrigation intervals × irrigation amounts were not significant but the location effect was significant, the comparison of the means was done separately for each location. Finally, 3) if the effects of location × irrigation intervals × irrigation amount as well as location were not significant, the means of the two locations were compared.

3. Results and discussion

3.1. Bunch weight, yield, and water use efficiency

The location had a significant effect on bunch weight (Table 3). Therefore, analysis of this parameter was done separately for each location. As presented in Table 4, In L_1, the highest bunch weight was obtained by P50V100. But, due to the insignificant difference of P100V70 treatment with this treatment, P100V70 is considered as superior treatment in terms of water saving and reducing irrigation costs. Also, P100V70 treatment in L_2 significantly increased the bunch weight. About the yield, according to the table of variance analysis and the lack of location effect (Table 3), the mean of both locations was compared for each treatment and the highest yield per tree was obtained by P100V70 in both locations, while treatment of P150V100 produced the lowest bunch weight and yield. The location had a significant effect on water use efficiency. According to Table 4, in L_1, different irrigation periods and rates did not have a significant effect, but in L_2, P100V70 caused a significant increase in water use efficiency compared to other treatments.

The effect of water availability on plant growth is due to changes in stomatal conductance, carbon uptake, and turgor pressure potential of plant tissues. The effect of DI on fruit yield and quality depends on the phenological stage of vegetative and reproductive growth, duration and severity of water restriction, and difference between the species. In stonefruits, plant water status has been well documented as a factor affecting the level of tree's yield (Intrigliolo and Castel, 2006), but in citrus trees there may not be interactive between the deficit irrigation and tree's yield (Pérez-Pérez et al., 2008a), so, needing to examine different species in one season. In the 'Lane Late Navel' citrus, during four seasons, water saving up to 19% was feasible without reducing the yield by applying a daily water stress of 70 MPa and RDI of 50% ETc irrigation limitations from July to mid-September (Ballester et al.,

Table 3
ANOVA of irrigation treatment effects (different periods and volumes) on bunch weight, yield, water use efficiency (WUE) and wilting damage at two locations of 'Mazafati' date trees.

Source of Variation	df	MS									
		Bunch Weight	Yield	WUE	Wilting and Dropping						
					Hababuk	Kimri	beginning Khalal	during Khalal	damage	Harvest	Total
Location (L)	1	20.80**	243.90^{ns}	0.09*	21.87^{ns}	55.47**	16.1^{ns}	8.33^{ns}	25.37^{ns}	36.05^{ns}	181.42^{ns}
eL	6	1.28^{ns}	115.78^{ns}	0.01^{ns}	18.40^{ns}	1.95^{ns}	6.55*	2.21^{ns}	11.82*	31.48*	34.30^{ns}
Period (P)	2	12.64***	694.62***	0.07***	181.69***	0.28^{ns}	7.30*	8.12*	63.57***	407.77***	587.77***
Volume (V)	1	0.96^{ns}	10.08^{ns}	0.02^{ns}	0.80^{ns}	2.61^{ns}	2.80^{ns}	0.36^{ns}	7.92^{ns}	40.33^{ns}	51.91^{ns}
P*V	2	0.76^{ns}	59.51^{ns}	0.006^{ns}	26.56^{ns}	8.04*	0.19^{ns}	2.70^{ns}	3.32^{ns}	27.80^{ns}	77.99*
L*P	2	3.45^{ns}	30.34^{ns}	0.003^{ns}	358.43***	0.29^{ns}	0.37^{ns}	0.47^{ns}	17.91*	42.02*	515.48***
L*V	1	1.68^{ns}	74.50^{ns}	0.007^{ns}	1.92^{ns}	12.0*	2.25^{ns}	0.14^{ns}	23.10*	51.25*	9.11^{ns}
L*P*V	2	0.19^{ns}	54.80^{ns}	0.005^{ns}	38.73^{ns}	0.93^{ns}	0.77^{ns}	0.69^{ns}	0.72^{ns}	11.09^{ns}	25.98^{ns}
Error	30	1.09	55.21	0.006	12.79	2.14	2.16	1.89	4.68	10.34	16.80
Total	47										

(ns) not significant. * Significant at P = 0.05. ** Significant at P = 0.01. *** Significant at P = 0.001.

Table 4
Bunch weight, total yield and water use efficiency (WUE) at harvest of 'Mazafati' dates as affected by irrigation treatments (different periods and volumes) at two locations.

Interaction of Main Factors		Bunch Weight (kg)		Yield (kg/tree)	WUE (kg/m^3)	
		L_1	L_2	Mean L_1, L_2	L_1	L_2
P50	V70	7.75^{abc}	5.82^{b}	52.91^{cd}	0.59^{ab}	0.54^{b}
	V100	8.37^{a}	5.52^{b}	56.32^{bc}	0.60^{ab}	0.54^{b}
P100	V70	8.1^{a}	7.8^{a}	64.68^{a}	0.71^{a}	0.68^{a}
	V100	7.92^{ab}	6.55^{ab}	60.70^{ab}	0.70^{a}	0.53^{bc}
P150	V70	6.27^{bc}	5.67^{b}	50.72^{cd}	0.60^{ab}	0.49^{bc}
	V100	6.1^{c}	5.25^{b}	48.55^{d}	0.55^{b}	0.44^{c}

Means within each column followed by the same letter are not significantly different at P = 0.05 level.
(P: Irrigation intervals at 50, 100 and 150 ETc, V: Irrigation levels of 70% and 100% ETc).

2013). Non-irrigation of mango trees in South Africa during the winter months (development and expansion of flower buds) increased production by up to 9%, decreased water consumption by 20%, and did not have a negative impact on fruit size (Mostert and Hoffman, 1996). Application of water stress in four different 5-week periods after flowering up to fruit maturation of banana showed that water stress in the first and last 5-week after flowering, had the lowest and highest yields respectively (Hegde and Srinivas, 1989). In 'Khadravi' date, soil moisture in the zone of root development during ripening was about 25% of field capacity, but no significant decrease was observed in leaf growth, and no significant difference was observed between treatments in terms of yield and fruit quality (Furr et al., 1952).

3.2. Bunch wilting and dropping

Wilt and drop percentage of fruits at six stages of fruit growth and development were measured. In the Kimri stage, according to Table 3, due to the significance of the location effect, the analyzes were performed separately for each location. There was no significant difference among levels in any of the stages, this means that water restriction up to 70% ET_C did not cause disruption in fruit growth. Except from the Kimri stage, in the other stages, the wilting percent was significant due to the irrigation intervals. So, according to Table 5, up to the Kimri stage and the beginning of the Khalal stage, the shortest irrigation interval (P50) was effective in reducing dropping, but after this stage, the irrigation interval of P100 controlled the dropping. Also, in total, P100V70 treatment showed the highest control of the disorder. The P150 treatments at both irrigation levels, except the harvest stage, caused the highest dropping of fruit, while P50 treatment showed the highest wilt and drop at harvest. It should be mentioned that the P150V100 treatment was partially close to the amount and interval of the traditional irrigation by the palm growers of the two locations.

Deficit irrigation, depending on the time of its application, may increase the flower buds in the trees, and during flowering and setting the fruit can affect the dropping of young flowers and fruits (Pérez-Pérez et al., 2008b). Repeated irrigation in the 3-year period on palm trees of Maktum cultivar caused more growth, late ripening of fruit and larger fruit production, while the amount of damage caused by the black tip and the fruit shrinkage was high (Sharples and Hilgeman, 1951). Drought stress in persimmon during flowering caused increased fruit dropping and, depending on the time of its application, reduced the growth of leaves and flower buds, increased intake of minerals, especially potassium (Ben-Arie et al., 2008). In persimmon, there was no significant difference between the amount of natural dropping among the water stress levels in the advanced stages of fruit development. This showed that difference in the number of fruit was probably due to the response to irrigation in the early stages of the reproductive cycle, such as flower induction, differentiation, and fruitset (Kanety et al., 2014).

3.3. Fruit physical properties

According to Table 6, the mean fruit weight in two locations was significant, so that in L_1, irrigation intervals of 50 and 100 compared to irrigation intervals of 150 at both levels of irrigation increased fruit weight, but in L_2, P50V100 and P150V70 treatments reduced mean weight of fruits (Table 7). Also, according to the results of Tables 6 and 7, the fruit length was not affected by the location and the mean of the two locations indicated that irrigation intervals of 100 at both levels of irrigation significantly increased the fruit length, but P50V100 and P150V70 treatments significantly decreased this parameter. According to the mentioned tables, the fruit firmness was not affected by the location, but irrigation volume had a significant effect, such that irrigation level of 70% in different irrigation intervals increased the firmness compared to the irrigation level of 100%, however, this increase was only significant at 50 irrigation intervals and P50V70 caused the highest fruit firmness while the P50V100 caused the lowest between all treatments.

Deficit irrigation strategies lead to a change in carbon allocation patterns, increased fruit growth versus vegetative growth and increased plant productivity. The cellular expansion of the fruit is more affected by water stress than its cell division. The expansion of the cell can occur only when the turgor pressure is greater than the cell wall resistance. The stress threshold of water greatly blocks the cells and cell growth

Table 5
Wilting damage percentage of 'Mazafati' dates as affected by irrigation treatment (different periods and volumes) at two plantations.

Interaction of Main Factors		Wilting and Dropping (%)							
		Hababuk	Kimri		The beginning Khalal	During the Khalal	Damage stage	Harvest	Total
		Mean L_1 and L_2	L_1	L_2	Mean L_1 and L_2	Mean L_1 and L_2	Mean L_1 and L_2	Mean L_1 and L_2	Mean L_1 and L_2
P50	V70	13.03^{bc}	2.25^{b}	5.82^{a}	2.83^{ab}	2.33^{ab}	6.70^{bc}	19.57^{a}	48.50^{abc}
	V100	10.57^{c}	4.87^{a}	5.52^{a}	2.12^{b}	1.62^{b}	7.62^{bc}	18.37^{a}	45.49^{bc}
P100	V70	16.53^{ab}	3.32^{ab}	6.8^{a}	2.35^{ab}	1.22^{b}	5.97^{c}	7.12^{d}	38.25^{d}
	V100	19.2^{a}	3.22^{ab}	4.62^{a}	2.07^{b}	1.55^{b}	5.82^{c}	10.70^{dc}	43.25^{cd}
P150	V70	17.1^{ab}	4.27^{ab}	6.67^{a}	3.75^{a}	2.35^{ab}	8.97^{ab}	13.10^{bc}	50.75^{ab}
	V100	17.67^{ab}	3.35^{ab}	4.75^{a}	3.26^{ab}	3.18^{a}	10.63^{a}	16.22^{ab}	54.99^{a}

Means within each column followed by the same letter are not significantly different at P = 0.05 level.
(P: Irrigation intervals at 50, 100 and 150 ETc, V: Irrigation levels of 70% and 100% ETc).

decreases due to the low turgor pressure (Shao et al., 2008). In peach, the amount of fruit dry matter increased with low irrigation stress, which means that the water flow to the fruit is more limited than carbohydrates. Low leaf stomatal conductance reduced the peach fruit weight and size in the harvest without affecting the number of fruits per tree. Water stress increased the concentration of lignin and the firmness of the peach fruit. The positive correlation between the firmness of peach fruit and the concentration of cell wall materials confirmed the results of the increase in the fruit firmness (Rahmati et al., 2015). Water stress in citrus during the flowering stage and fruit set threatened the yield with decreasing fruit diameter, and water limitations during the last stage of fruit growth and maturation reduced the yield by reducing the fruit weight. While water limits of 50% ETc during the months of July and August allowed to reduce water use without any reduction of yield and fruit size in citrus (García-Tejero et al., 2010). Four DI seasons from July to mid-September at 'Lane Late Navel' citrus reduced 9% of fruit weight, although yields did not decrease, and fruits at the end of the year reached 81% of their final size, but, the 'Nulz' clementine mandarin, with a shorter growth time, gained only about 71% of size, so the threshold for irrigation reduction in 'Navel' oranges was higher, which did not reduce the yield (Ballester et al., 2013). Also, water limitation in citrus led to the decomposition of cell wall polymers and further decrease in the osmotic potential of the fruit and ultimately the fruit firmness (García-Tejero et al., 2010). Deficit irrigation during early fruit growth over the years reduced the fruit size in 'Leccino' olive (Rapoport et al., 2004).

3.4. Chemical properties

According to Tables 6 and 7, TSS of fruit was affected by the location and it was higher in L_2 compared L_1 at all treatment combinations. In L_1, different treatments did not show significant effect on this parameter, but in L_2, irrigation interval of P150 at both levels of 70 and 100% and P100 at level of 70% showed the highest TSS levels. Different treatments at two locations did not have a significant effect on the amount of fruit acid (0.29–0.27%) (data not shown). In the case of soluble sugars, the location had significant effect at 5% level on this parameter, so that at L_1 soluble sugars was lower than L_2. The effect of irrigation intervals was also significant for this parameter, and by increasing the irrigation intervals the soluble sugars also increased. Location did not have a significant effect on the total phenol content of the fruit (Table 6). Therefore, the mean of total phenol content in two locations were compared. Although only P150v100 was significantly different with other treatments, but higher water volume (V100) resulted to lower total phenols in all treatments (Table 7). The amount of fruit starch was effected by the location at harvest time. The effect of treatments in two locations was largely similar, so that the irrigation amount of 100% ETc in different irrigation intervals significantly increased this fruit parameter. Among these treatments, P150V70 showed the lowest starch content in fruit (Tables 6 and 7).

The concentration of fruit's non-structural compounds is directly affected by water stress. The amount of material entering the fruit is affected by the osmotic regulation. Mild osmosis stress may lead to reduced plant growth and increased concentrations of secondary metabolites. Under water stress condition and decreased CO_2 absorption, carbon should be allocated to the synthesis of the primary metabolites for the growth of the fruit. However, the increase and accumulation of polyphenols in response to RDI in peach, grape and olive has been reported (Austin and Wilcox, 2011; Buendía et al., 2008; Tovar et al., 2002). It can be suggested that an active accumulation of sugars accompanied by the lower water potential and higher concentration of solutes would increase the TSS of the fruit under lower water condition (Intrigliolo and Castel, 2010). The concentration of total carbohydrates and organic acids in peach at intensive water stress during harvest

Table 6
ANOVA of irrigation treatment effects (different periods and volumes) on physical and biochemical characteristics of fruit of 'Mazafati' date trees at two locations.

Source of Variation	df	MS							
		Fruit Weight	Fruit Length	Fruit Diameter	Fruit Firmness	TSS	Soluble Sugars	Total Phenol	Starch
Location (L)	1	66.64^{***}	1.05^{ns}	0.20^{ns}	0.03^{ns}	719.97^{***}	672.07^{*}	0.14^{ns}	116.09^{*}
eL	6	1.25^{ns}	0.50^{ns}	0.03^{ns}	0.44^{ns}	11.85^{ns}	23.66^{ns}	0.08^{**}	11.81^{ns}
Period (P)	2	14.04^{***}	1.08^{*}	0.01^{ns}	0.95^{ns}	68.16^{**}	115.93^{*}	0.07^{*}	317.87^{***}
Volume (V)	1	0.21^{ns}	0.04^{ns}	0.00^{ns}	4.81^{***}	2.29^{ns}	8.20^{ns}	0.21^{**}	711.40^{***}
P*V	2	3.66^{ns}	0.76^{ns}	0.03^{ns}	1.15^{*}	4.68^{ns}	4.33^{ns}	0.01^{ns}	76.11^{***}
L*P	2	9.09^{**}	0.53^{ns}	0.10^{ns}	0.36^{ns}	65.54^{**}	31.05^{ns}	0.01^{ns}	28.34^{*}
L*V	1	0.44^{ns}	0.11^{ns}	0.20^{ns}	0.56^{ns}	8.25^{ns}	26.71^{ns}	0.05^{ns}	1.21^{ns}
L*P*V	2	2.68^{ns}	0.80^{ns}	0.01^{ns}	0.15^{ns}	10.10^{ns}	5.58^{ns}	0.03^{ns}	20.44^{ns}
Error	30	1.55	0.32	0.08	0.29	8.45	30.69	0.02	6.55
Total	47								

(ns) not significant. * Significant at P = 0.05. ** Significant at P = 0.01. *** Significant at P = 0.001.

Table 7
Physical and biochemical characteristics of 'Mazafati' fruit dates as affected by irrigation treatments (different periods and volumes) at two locations.

Interaction of Main Factors		Fruit Weight (g)		Fruit Length (cm)	Fruit Diameter (cm)	Fruit Firmness (kg/cm^2)	TSS (Brix %)		Soluble Sugars (%DW)		Total Phenol (mg g^{-1} DW)	Starch (mg g^{-1} DW)	
		L_1	L_2	Mean L_1 and L_2	Mean L_1 and L_2	Mean L_1 and L_2	L_1	L_2	L_1	L_2	Mean L_1 and L_2	L_1	L_2
P50	V70	11.55^{a}	7.82^{ab}	3.31^{abc}	2.06^{a}	3.56^{a}	55.55^{a}	60.07^{b}	57.05^{a}	65.78^{ab}	1.35^{a}	25.50^{b}	21.20^{bc}
	V100	10.87^{a}	6.77^{b}	3.07^{bc}	2.07^{a}	2.32^{c}	56.62^{a}	60.52^{b}	59.53^{a}	64.04^{b}	1.24^{a}	32.78^{a}	33.70^{a}
P100	V70	11.32^{a}	9.30^{a}	3.71^{a}	1.96^{a}	2.93^{b}	56.32^{a}	65.80^{a}	63.03^{a}	70.50^{ab}	1.36^{a}	24.22^{bc}	22.50^{b}
	V100	11.85^{a}	7.80^{ab}	3.57^{ab}	2.07^{a}	2.72^{bc}	57.60^{a}	61.85^{b}	63.79^{a}	66.79^{ab}	1.27^{a}	34.49^{a}	33.29^{a}
P150	V70	8.52^{b}	6.92^{b}	2.91^{c}	2.03^{a}	3.52^{a}	56.82^{a}	68.55^{a}	61.79^{a}	72.52^{a}	1.28^{a}	21.54^{c}	17.27^{c}
	V100	8.85^{b}	8.50^{ab}	3.47^{abc}	1.97^{a}	3.07^{ab}	55.65^{a}	68.25^{a}	60.54^{a}	71.01^{ab}	1.08^{b}	26.13^{b}	18.04^{c}

Means within each column followed by the same letter are not significantly different at P = 0.05 level.
(P: Irrigation intervals at 50, 100 and 150 ETc, V: Irrigation levels of 70% and 100% ETc).

Table 8
ANOVA of irrigation treatment effects (different periods and volumes) on antioxidant enzymes activities of fruit and leaves of 'Mazafati' date trees at two locations.

Source of Variation	df	MS							
		Peroxidase (POD)		Superoxide Dismutase (SOD)		Polyphenol Oxidase (PPO)		Catalase (CAT)	
		Fruit	Leaf	Fruit	Leaf	Fruit	Leaf	Fruit	Leaf
Location (L)	1	0.15^{ns}	0.82^{ns}	306.58^{ns}	99.18^{ns}	58.30^{ns}	6.67^{ns}	13.44^{ns}	117.50^{ns}
eL	6	0.58^{ns}	64.06**	56.39^{ns}	27.33^{ns}	11.23*	45.82^{ns}	9.10^{ns}	49.43^{ns}
Period (P)	2	0.35^{ns}	53.93*	69.21^{ns}	27.82^{ns}	14.41^{ns}	72.66*	143.68**	391.02***
Volume (V)	1	2.54*	428.10***	106.95^{ns}	101.50^{ns}	30.24*	99.47*	153.36*	187.62*
P*V	2	0.06^{ns}	46.65*	44.55^{ns}	25.43^{ns}	6.97^{ns}	9.58^{ns}	0.13^{ns}	202.85*
L*P	2	0.17^{ns}	0.22^{ns}	43.94^{ns}	49.67^{ns}	0.82^{ns}	15.72^{ns}	18.56^{ns}	34.76^{ns}
L*V	1	0.32^{ns}	32.78^{ns}	5.78^{ns}	8.16^{ns}	4.26^{ns}	13.33^{ns}	0.06^{ns}	67.92^{ns}
L*P*V	2	0.36^{ns}	44.45^{ns}	8.45^{ns}	34.69^{ns}	8.94^{ns}	56.97^{ns}	77.31^{ns}	45.50^{ns}
Error	30	0.45	13.66	40.22	26.31	4.55	20.77	25.29	41.98
Total	47								

(ns) not significant. * Significant at P = 0.05. ** Significant at P = 0.01. *** Significant at P = 0.001.

Table 9
Antioxidant enzymes activities (U min^{-1} g^{-1} FW) of 'Mazafati' date palm fruit and leaves at wilting damage stage as affected by irrigation treatments (different periods and volumes) at two locations.

Interaction of Main Factors		Peroxidase (POD)		Superoxide Dismutase (SOD)		Polyphenol Oxidase (PPO)		Catalase (CAT)	
		Fruit	Leaf	Fruit	Leaf	Fruit	Leaf	Fruit	Leaf
P50	V70	3.17^{ab}	34.55^{cd}	61.42^{b}	59.21^{ab}	9.50^{bc}	19.50^{ab}	13.01^{bc}	20.82^{b}
	V100	2.85^{b}	42.97^{a}	61.97^{b}	57.57^{ab}	11.85^{a}	24.10^{a}	9.47^{c}	13.25^{c}
P100	V70	3.31^{ab}	31.69^{d}	68.69^{a}	62.77^{a}	8.80^{bc}	17.80^{b}	15.71^{ab}	14.87^{bc}
	V100	2.73^{b}	39.11^{ab}	62.61^{ab}	56.96^{b}	8.86^{bc}	20.23^{ab}	11.93^{bc}	19.12^{bc}
P150	V70	3.51^{a}	34.76^{cd}	66.51^{ab}	61.66^{ab}	8.18^{c}	16.81^{b}	18.92^{a}	29.85^{a}
	V100	3.03^{ab}	36.83^{bc}	63.08^{ab}	60.38^{ab}	10.53^{ab}	18.41^{b}	15.51^{ab}	21.31^{b}

Means within each column followed by the same letter are not significantly different at P = 0.05 level.
(P: Irrigation intervals at 50, 100 and 150 ETc, V: Irrigation levels of 70% and 100% ETc).

Table 10
ANOVA of irrigation treatment effects (different periods and volumes) on mineral contents of leaves of 'Mazafati' date trees at two locations.

Source of Variation	df	MS							
		N	P	K	Ca	Fe	Mn	Cu	Zn
Location (L)	1	0.23^{ns}	0.01^{ns}	0.06^{ns}	0.01^{ns}	352.62^{ns}	611.32^{ns}	25.08^{ns}	24.65^{ns}
eL	6	0.05^{ns}	0.01^{ns}	0.12^{ns}	0.04***	67.02^{ns}	115.81^{ns}	25.62**	36.20***
Period (P)	2	0.14^{ns}	0.03^{ns}	0.33^{ns}	0.03**	673.79*	53.76^{ns}	22.42^{ns}	22.94*
Volume (V)	1	0.01^{ns}	0.02^{ns}	0.35^{ns}	0.02*	2685.91***	231.88^{ns}	0.01^{ns}	12.40^{ns}
P*V	2	0.10^{ns}	0.01^{ns}	0.22^{ns}	0.01*	34.09^{ns}	92.08^{ns}	15.72^{ns}	15.35^{ns}
L*P	2	0.04^{ns}	0.01^{ns}	0.04^{ns}	0.01^{ns}	796.50*	15.11^{ns}	13.87^{ns}	15.26^{ns}
L*V	1	0.00^{ns}	0.01^{ns}	0.01^{ns}	0.01^{ns}	372.52^{ns}	9.45^{ns}	31.20*	38.52*
L*P*V	2	0.03^{ns}	0.01^{ns}	0.24^{ns}	0.01^{ns}	252.41^{ns}	33.68^{ns}	4.88^{ns}	4.87^{ns}
Error	30	0.04	0.01	0.18	0.01	181.51	55.61	7.20	6.63
Total	47								

(ns) not significant. * Significant at P = 0.05. ** Significant at P = 0.01. *** Significant at P = 0.001.

Table 11
Leaf mineral contents of 'Mazafati' date palm at wilting damage stage as affected by irrigation treatments (different periods and volumes) at two locations.

Interaction of Main Factors		Macro Elements (%)				Micro Elements (ppm)			
		N	P	K	Ca	Fe	Mn	Cu	Zn
P50	V70	0.99^{bc}	0.19^{ab}	0.70^{ab}	0.36^{bc}	126.36^{bc}	39.37^{abc}	9.12^{a}	9.87^{ab}
	V100	1.18^{ab}	0.25^{ab}	1.12^{a}	0.47^{a}	140.84^{ab}	40.10^{ab}	8.47^{ab}	10.21^{ab}
P100	V70	1.21^{a}	0.20^{ab}	0.77^{ab}	0.36^{bc}	136.36^{ab}	32.27^{c}	8.02^{ab}	9.02^{b}
	V100	1.23^{a}	0.18^{b}	0.92^{ab}	0.43^{ab}	148.68^{a}	42.10^{a}	10.22^{a}	12.25^{a}
P150	V70	1.10^{abc}	0.18^{b}	0.66^{b}	0.35^{c}	120.85^{c}	34.86^{bc}	7.73^{ab}	8.58^{b}
	V100	0.97^{c}	0.31^{a}	0.61^{b}	0.32^{c}	138.94^{ab}	37.50^{abc}	6.12^{b}	8.07^{b}

Means within each column followed by the same letter are not significantly different at P = 0.05 level.
(P: Irrigation intervals at 50, 100 and 150 ETc, V: Irrigation levels of 70% and 100% ETc).

mainly increased by reducing the fruit dilution, while the concentration of polyphenols was strongly reduced through metabolic effects (Rahmati et al., 2015). In peach, fruit growth reduced under water stress, thus by decreasing the use of glucose and fructose in glycolysis, their content increased. However, since water stress caused precocity, there was no significant difference with control in glucose and fructose during harvest (Rahmati et al., 2015). Water deficit in the final stage of fruit growth in stonefruits reduces fruit yeild, but leads to positive aspects of increasing TSS and precocity of fruit (Besset et al., 2001). Deficit irrigation reduces the growth of peach fruit, so the respiration of growth and maintenance should be lower. Reducing vegetative growth and peach tree load in DI caused the product to be more exposed to light and therefor photo oxidation, that decreased some of the antioxidant contents of fruits, including vitamin C and carotenoids, but the content of phenolic compounds, mainly anthocyanin and procyanidin, increased by ultraviolet radiation to counteract the oxidative damage of tissue (Buendía et al., 2008). During water stress, the main chemical components of date fruit including sugars, fibers, pectin, tannins and vitamins were reduced (Ahmed et al., 1995). The total dry matter content of 'Khalas' date increased significantly under water stress at once a week irrigation, but TSS, pectin, sucrose, tannin, and pH did not differ significantly between irrigation treatments (Al-Yahyai and Al-Kharusi, 2012). Deficit irrigation of citrus trees on Cleopatra rootstock caused reduction of water percentage, but increased sugar accumulation and TSS due to redistribution of plant photosynthesis towards fruit, however, intense water stress caused further increase in acids compared with sugars, so the quality of the fruit reduced (Romero et al., 2006). Irrigation of olive plants with a 60% ETc retained the amount of soluble sugars in the leaf, similar to the full irrigation treatment, but the starch content of the leaves decreased significantly. This was explained to be primarily associated with osmotic regulation of tissue (Bacelar et al., 2007). As explained by many researchers, in plants after exposure to stress, osmotic compounds such as soluble sugars, amino acids such as proline, aspartic acid and glutamic acid, ammonium compounds and hydrophilic proteins accumulate, and one of the main sources of these osmolites is starch reserves.

3.5. Antioxidant enzyme activities

According to Table 8, Activity of different enzymes in leaf and fruit were the same in two locations. The irrigation level of 70% ETc in all three irrigation intervals increased the activity of POD enzyme in the fruit. However, in the leaves, 100% ETc in all three irrigation intervals increased the activity of this enzyme, but this increase was significant only in irrigation intervals of 50 and 100 compared to the 150 treatment although it was higher at P100V70 treatment in both leaves and fruits (Table 9). SOD activity was not significantly different in leaves and fruits of different treatments. Regarding the activity of PPO in fruit, 100% irrigation of ET_C in irrigation intervals 50 and 150, significantly increased the enzyme activity. The activity of this enzyme in leaf with irrigation rate of 70% ETc was lower than 100% Etc at all irrigation intervals. Also by increasing the irrigation intervals the PPO activity decreased. The activity of CAT enzyme in fruit significantly increased with 70% irrigation of ETc at all irrigation intervals. The activity of this enzyme in leaf increased at irrigation intervals of 50 and 150 with irrigation level of 70% but decreased at 100% level. The irrigation treatment of P150V70 showed the highest CAT activity between the treatments.

Cells are equipped with enzymatic antioxidants to remove the ROS, and increasing the activity of antioxidant enzymes in plant species is for adaptation to stress. However, severe stress may lead to damage to the antioxidant system of the cell and reduction of the activity of these enzymes leading to production of more active oxygen species. Effective degradation of ROS requires coordinated action of several antioxidant enzymes to provide good results for stress tolerance. Water deficit in two cultivars of olive, different for tolerance to water stress, increased the activity of CAT, GR and APX, but did not have a significant effect on SOD activity in both cultivars, and in the 'Chemlali' olive, oxidative damage was less due to the higher activity of these enzymes (Guerfel et al., 2009). In drought stress, an increase in ABA and apoplastic pH resulted in increased POD activity in tomato, and therefore increase of cross-linking of cell phenols due to increased enzymatic activity of fruit pericarp, also affected the cell growth and ultimately decreased the diameter of the fruit (Mingo et al., 2003). In three olive cultivars exposed to water stress for one year, specific antioxidant defense was achieved, including increased activity of SOD, APX and CAT. In contrast, PPO activity was reduced and led to the maintenance of phenols at acceptable levels (Ahmed et al., 2009).

3.6. Changes of mineral elements in leaves

The location had no significant effect on the concentration of macro and micro elements measured in the leaves (Table 10). Also, different treatments did not have a significant effect on the concentration of leaf N, P, K, Mn and Cu at the time of the disorder. Irrigation level of 70% ETc in irrigation intervals of 50 and 100 significantly decreased the Ca concentration of leaves (Table 11). For Fe, irrigation level of 70% ETc only at irrigation interval of 150 significantly reduced the concentration of this element in the leaf. Also, according to these tables, irrigation interval of 150 in two levels of irrigation significantly reduced the Zn concentration of leaves, and in P100 interval the V70 had significantly lower Zn than V100.

There is a close relation between water availability and minerals absorption, because the absorption of soluble minerals depends on the flow of water in the path of soil to the roots. The relationship between minerals content and irrigation limitation requires accurate estimation. Benefits of DI include reducing minerals leaching, as well as reducing the saturation of minerals and biocides in the root zone. Excess superoxide in chloroplasts under severe water stress conditions can enhance the concentration of iron-catalyzed OH formation and damage to the mechanism of iron absorption control in the roots (Price and Hendry, 1991). Early-season irrigation limitations in pear trees resulted in a

decrease of calcium concentration and disruption of its storage in fruits (Marsal et al., 2012). In deficit irrigation of grapes and olives as well as partial root zone drying irrigation of apples and tomatoes, the concentration of leaf and fruit minerals including nitrogen, phosphorus, potassium, calcium and magnesium were not affected, although their content in soil and commercially irrigated plants were better than DI or PRD methods (Nakajima et al., 2004). In DI of mango during three subsequent seasons only leaf minerals including phosphorus, magnesium and manganese were affected (Zuazo et al., 2011).

4. Conclusion

Fruit wilting and dropping is part of a highly organized development of a plant in response to stresses. The sensitivity of date palms to stress concurrent with the maturity of tree increases due to, firstly, a relatively high growth rate, and secondly, the presence of fruits on adult trees. There is also evidence that high yield may increase the sensitivity of the plant to possible stress. In this research, irrigation limitations were applied for the control of vegetative and reproductive growth as a strategy to reduce fruit drying and dropping due to stress. Under experimental condition of this research when the amount of irrigation decreased, yield of date palms did not reduce significantly and stress was not harmful, and the best result for the decrease in fruit wilting and dropping was achieved with 70% ETc irrigation at 100 mm evaporation interval, but this treatment caused significant water use efficiency only in the second orchard location. Irrigation amount in superior treatment (P100V70) for control of the disorder was 1380 to 1480 mm per year, which according to the results, this amount of irrigation led to an increase of approximately 33% of the minimum yield and a reduction of 30% from the maximum wilting and drying of the fruits. The question is whether the amount of water saving (85 to 102 mm) in the treatment of maximum product can be further increased? According to the non-significant effects of applied DI, new research with a further reduction in the irrigation is required. The water saving should be to the extent that, the diminishing in the profit resulting from the reduction in yield is compensated by reducing production costs and reducing the dropping disorder.

References

Ahmed, I., Al-Gharibi, K., Daar, A., Kabir, S., 1995. The composition and properties of date proteins. Food Chem. 53, 441–446.

Ahmed, C.B., Rouina, B.B., Sensoy, S., Boukhris, M., Abdallah, F.B., 2009. Changes in gas exchange, proline accumulation and antioxidative enzyme activities in three olive cultivars under contrasting water availability regimes. Environ. Exp. Bot. 67, 345–352.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration-Guidelines for Computing Cop Water Requirements-FAO Irrigation and Drainage Paper 56 300 FAO, Rome, D05109.

Al-Yahyai, R., Al-Kharusi, L., 2012. Sub-optimal irrigation affects chemical quality attributes of dates during fruit development. Afr. J. Agric. Res. 7, 1498–1503.

Austin, C.N., Wilcox, W.F., 2011. Effects of fruit-zone leaf removal, training systems, and irrigation on the development of grapevine powdery mildew. Am. J. Enol. Vitic. 62, 193–198.

Bacelar, E.A., Santos, D.L., Moutinho-Pereira, J.M., Lopes, J.I., Gonçalves, B.C., Ferreira, T.C., Correia, C.M., 2007. Physiological behaviour, oxidative damage and antioxidative protection of olive trees grown under different irrigation regimes. Plant Soil 292, 1.

Ballester, C., Castel, J., Intrigliolo, D., Castel, J., 2013. Response of 'Navel Lane Late' citrus trees to regulated deficit irrigation: yield components and fruit composition. Irrig. Sci. 31, 333–341.

Beauchamp, C., Fridovich, I., 1971. Superoxide dismutase: improved assays and an assay applicable to acrylamide gels. Anal. Biochem. 44, 276–287.

Ben-Arie, R., Zilkah, S., Klein, I., Gamrasni, D., 2008. Persimmon and environment: soil and water management for high quality fruit production. Adv. Hortic. Sci. 22 (4), 286–293.

Benavides, M.P., Gallego, S.M., Tomaro, M.L., 2005. Cadmium toxicity in plants. Braz. J. Plant Physiol. 17, 21–34.

Bergmeyer, H.U., Bergmeyer, J., Grassl, M., 1974. Methods of enzymatic analysis. Samples, Reagents, Assessment of Results 2. Verlag Chemie, pp. 360.

Besset, J., Génard, M., Girard, T., Serra, V., Bussi, C., 2001. Effect of water stress applied during the final stage of rapid growth on peach trees (cv. Big-Top). Sci. Hortic. 91, 289–303.

Buendía, Ba., Allende, A., Nicolás, E., Alarcón, J.J., Gil, M.I., 2008. Effect of regulated deficit irrigation and crop load on the antioxidant compounds of peaches. J. Agric. Food Chem. 56, 3601–3608.

Chalmers, D., 1981. Control of peach tree growth and productivity by regulated water supply, tree density, and summer pruning. J. Amer. Soc. Hort. Sci. 106, 307–312.

Chapman, H., Pratt, P., 1961. Plant analysis. Methods of analysis for soils. Plants Waters 56–64.

Dubois, M., Gilles, K.A., Hamilton, J.K., Rebers, P., Smith, F., 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28, 350–356.

Furr, J., Currlin, E., Armstrong, W., 1952. Effects of Water Shortage During Ripening and of Nitrogen Fertilization on Yield and Quality of 'Khadrawy' Dates. Report. 29th Annu. Date Grs' Inst., Coachella. 10-12 pp.. .

García-Tejero, I., Romero-Vicente, R., Jiménez-Bocanegra, J., Martínez-García, G., Durán-Zuazo, V., Muriel-Fernández, J., 2010. Response of citrus trees to deficit irrigation during different phenological periods in relation to yield, fruit quality, and water productivity. Agric. Water Manag. 97, 689–699.

Goldhamer, D., Beede, R., 2004. Regulated deficit irrigation effects on yield, nut quality and water-use efficiency of mature pistachio trees. J. Hortic. Sci. Biotechnol. 79, 538–545.

Gribaa, A., Dardelle, F., Lehner, A., Rihouey, C., Burel, C., Ferchichi, A., Driouich, A., Mollet, J.C., 2013. Effect of water deficit on the cell wall of the date palm (Phoenix dactylifera 'Deglet nour', Arecales) fruit during development. Plant Cell Environ. 36, 1056–1070.

Guerfel, M., Ouni, Y., Boujnah, D., Zarrouk, M., 2009. Photosynthesis parameters and activities of enzymes of oxidative stress in two young 'Chemlali'and 'Chetoui'olive trees under water deficit. Photosynthetica 47 (3), 340–346.

Hegde, D., Srinivas, K., 1989. Irrigation and nitrogen fertility influences on plant water relations, biomass, and nutrient accumulation and distribution in banana cv. Robusta. J. Hortic. Sci. 64, 91–98.

Hillel, D., 2013. Advances in Irrigation. Elsevier.

Horwitz, W., 2000. Official Methods of Analysis 222 Association of Official Analytical Chemists Washington, DC 105 pages.

Intrigliolo, D., Castel, J., 2006. Performance of various water stress indicators for prediction of fruit size response to deficit irrigation in plum. Agric. Water Manag. 83, 173–180.

Intrigliolo, D., Castel, J., 2010. Response of plum trees to deficit irrigation under two crop levels: tree growth, yield and fruit quality. Irrig. Sci. 28, 525–534.

Kanety, T., Naor, A., Gips, A., Dicken, U., Lemcoff, J.H., Cohen, S., 2014. Irrigation influences on growth, yield, and water use of persimmon trees. Irrig. Sci. 32, 1–13.

Li, L., Steffens, J.C., 2002. Overexpression of polyphenol oxidase in transgenic tomato plants results in enhanced bacterial disease resistance. Planta 215, 239–247.

Liebenberg, P.J., Zaid, A., 1999. Date palm irrigation. In: Zaid, A. (Ed.), Date Palm Cultivation. Plant Production and Protection Paper. 156. FAO, Rome pp. 130–143.

Marsal, J., Lopez, G., Mata, M., Girona, J., 2012. Postharvest deficit irrigation in 'Conference'pear: effects on subsequent yield and fruit quality. Agric. Water Manag. 103, 1–7.

McCready, R., Guggolz, J., Silviera, V., Owens, H., 1950. Determination of starch and amylose in vegetables. Anal. Chem. 22, 1156–1158.

Mingo, D.M., Bacon, M.A., Davies, W.J., 2003. Non-hydraulic regulation of fruit growth in tomato plants (Lycopersicon esculentum cv. Solairo) growing in drying soil. J. Exp. Bot. 54, 1205–1212.

Mireei, S.A., Sadeghi, M., 2013. Detecting bunch withering disorder in date fruit by near infrared spectroscopy. J. Food Eng. 114, 397–403.

Mostert, P., Hoffman, J., 1996. Water requirements and irrigation of mature mango trees. V International Mango Symposium 455, 331–338.

Mpelasoka, B.S., Behboudian, M., Ganesh, S., 2001. Fruit quality attributes and their interrelationships of'Braeburn'apple in response to deficit irrigation and to crop load. Gartenbauwissenschaft 66, 247–253.

Nakajima, H., Behboudian, M.H., Greven, M., Zegbe-Domínguez, J.A., 2004. Mineral contents of grape, olive, apple, and tomato under reduced irrigation. Mineralstoffgehalte von Weintrauben, Oliven, Äpfeln und Tomaten bei reduzierter Bewässerung. J. Plant Nutr. Soil Sci. 167, 91–92.

Naor, A., 2005. Irrigation scheduling of peach-deficit irrigation at different phenological stages and water stress assessment. VI International Peach Symposium 713, 339–350.

Pérez-Pérez, J., Romero, P., Navarro, J., Botía, P., 2008a. Response of sweet orange cv 'Lane late'to deficit-irrigation strategy in two rootstocks. II: flowering, fruit growth, yield and fruit quality. Irrig. Sci. 26, 519–529.

Pérez-Pérez, J., Romero, P., Navarro, J., Botía, P., 2008b. Response of sweet orange cv 'Lane late'to deficit irrigation in two rootstocks. I: water relations, leaf gas exchange and vegetative growth. Irrig. Sci. 26, 415–425.

Price, A.H., Hendry, G., 1991. Iron-catalysed oxygen radical formation and its possible contribution to drought damage in nine native grasses and three cereals. Plant Cell Environ. 14, 477–484.

Qaddoury, A., Amssa, M., 2003. Endogenous phenolic contents, peroxidase and polyphenoloxidase activities in date palm (Phoenix dactylifera L.) offshoots related to rooting ability. Acta Physiol. Plant. 25, 417–421.

Rahmati, M., Vercambre, G., Davarynejad, G., Bannayan, M., Azizi, M., Génard, M., 2015. Water scarcity conditions affect peach fruit size and polyphenol contents more severely than other fruit quality traits. J. Sci. Food Agric. 95, 1055–1065.

Rapoport, H.F., Costagli, G., Gucci, R., 2004. The effect of water deficit during early fruit development on olive fruit morphogenesis. J. Am. Soc. Hortic. Sci. 129, 121–127.

Romero, P., Navarro, J., Pérez-Pérez, J., García-Sánchez, F., Gómez-Gómez, A., Porras, I., Martinez, V., Botía, P., 2006. Deficit irrigation and rootstock: their effects on water relations, vegetative development, yield, fruit quality and mineral nutrition of Clemenules mandarin. Tree Physiol. 26, 1537–1548.

Selahvarzi, Y., Zamani, Z., Fatahi, R., Talaei, A.-R., 2017. Effect of deficit irrigation on

flowering and fruit properties of pomegranate (Punica granatum cv. Shahvar). Agric. Water Manag. 192, 189–197.
Shao, H.-B., Chu, L.-Y., Jaleel, C.A., Zhao, C.-X., 2008. Water-deficit stress-induced anatomical changes in higher plants. C. R. Biol. 331, 215–225.
Sharples, G., Hilgeman, R., 1951. The Influence of Irrigation and Bunch Management Upon Shrivel of the 'Maktoom' Date. Report. 28th Annu. Date Grs' Inst., Coachella. 1951. pp. 9–11.
Tovar, M.J., Romero, M.P., Girona, J., Motilva, M.J., 2002. L-Phenylalanine ammonia--lyase activity and concentration of phenolics in developing olive (Olea europaea L cv Arbequina) fruit grown under different irrigation regimes. J. Sci. Food Agric. 82, 892–898.
Velioglu, Y., Mazza, G., Gao, L., Oomah, B., 1998. Antioxidant activity and total phenolics in selected fruits, vegetables, and grain products. J. Agric. Food Chem. 46, 4113–4117.
Zegbe-Domınguez, J., Behboudian, M., Lang, A., Clothier, B., 2003. Deficit irrigation and partial rootzone drying maintain fruit dry mass and enhance fruit quality in 'Petopride'processing tomato (Lycopersicon esculentum, Mill.). Sci. Hortic. 98, 505–510.
Zhou, W., Leul, M., 1999. Uniconazole-induced tolerance of rape plants to heat stress in relation to changes in hormonal levels, enzyme activities and lipid peroxidation. Plant Growth Regul. 27, 99–104.
Zuazo, V.H.D., Pleguezuelo, C.R.R., Tarifa, D.F., 2011. Impact of sustained-deficit irrigation on tree growth, mineral nutrition, fruit yield and quality of mango in Spain. Fruits 66, 257–268.